0 EXECUTIVE SUMMARY

The Project "Integrated Surface and Groundwater Model for Lake Tohopekaliga (Lake Toho) Drawdown Project C-11849" has been carried out by DHI, Inc. and GeoModel, Inc. for the South Florida Water Management District.

The Florida Fish & Wildlife Conservation Commission has planned an extreme drawdown for Lake Toho starting in November 2001. Traditionally the Commission sponsors the drawdown projects while federal and local government organizations support the projects, for instance, with technical expertise. The present project is funded by SFWMD in support of the drawdown study.

The proposed Lake Toho drawdown study would temporarily modify the normal lake water level regulation schedule to 48.5 feet. The normal regulation schedule varies between 52-55 feet.

The objective of the present study is to develop an integrated surface water-groundwater model (ISGM) with the ability to predict potential impacts on the groundwater levels of the surficial aquifer.

The project area covers about 1100 square miles and includes approximately the entire water shed for Lake Cypress. The project area is shown in Figure 0-1.

The Lake Toho ISGM is based on the MIKE SHE modeling system, developed by DHI Water & Environment. The MIKE SHE modeling system is an integrated hydrologic modeling system that describes the entire land phase of the hydrologic system including coupled surface water and groundwater.

The hydraulic model component (MIKE11) of the Lake Toho ISGM includes all the major lakes and related hydraulic control structures. Moreover, it contains the major tributaries (Boggy Creek, Shingle Creek and Reedy Creek). The model also includes Fanny Bass creek and Fanny Bass Pond which are located next to the Sunset Fish farms. Sunset is located about 2 miles from Lake Toho's eastern shoreline.

The unsaturated zone, evapotranspiration and irrigation models are based on soil and land use maps and calculates water content in the unsaturated zone, actual evapotranspiration, irrigation demands and groundwater recharge.

The groundwater model component considers only the surficial aquifer and adopts a 2-dimensional approach. Exchange of water with the Upper Floridan aquifer is included as a general head boundary condition (head-dependent-flux).

The Lake Toho ISGM combines available field data within the project area in an integrated modeling framework. The model has been calibrated and validated against field data comprising both groundwater level data and surface water flow and stage data. The model gen-

erally has the ability to reproduce measured groundwater table with a precision of 1 foot. The uncertainty on predicted yearly runoff is generally within 10-20%. Considering uncertainties in meteorological data and in runoff measurements this appears as a reasonable uncertainty on predicted runoff (The model uses 16 rainfall gages to cover the entire 1100 square mile area). Moreover, the model has proven to be consistent with other studies conducted in the project area focusing on actual evapotranspiration and recharge of the Upper Floridan Aquifer. Hence, the model has demonstrated the ability to reproduce both measured stage data as well as the overall water balance within the project area. Overall the model appears to be scientifically sound, consistent and reliable with the ability to predict hydrologic impacts from stresses such as a lake water level drawdown.

The established ISGM has been applied to study impacts of the Lake Toho drawdown for 10 different scenarios. These scenarios are composed of 5 different climatic conditions representing different combinations of dry, normal and wet conditions. Each climate scenario has then been simulated both with and without lake drawdown. The results of the scenario simulations show that the groundwater impact zone does not extend beyond 4000-5000 feet from the edge of Lake Toho, less than half the distance to Sunset Tropicals fish farm.

An additional simulation for 1 climatic scenario has been conducted using a more detailed model of the Fanny Bass Pond area. The results of the local scale model scenario confirm the findings of the regional scale model, namely that the effects of the lake drawdown are localized to a narrow zone adjacent to the lake.

The main factor that controls the extent of the impact zone during the drawdown is the horizontal hydraulic conductivity of the aquifer. Sensitivity analyses have been conducted where this key parameter has been increased far beyond realistic limits to properties corresponding to those of a coarse sand/gravel aquifer. Under these highly exaggerated aquifer drainage conditions the model predicts a maximum impact at the distance of the Sunset Tropicals fish farm sunset of 0.2 feet.

In summary the findings of the project is that the extent of the groundwater impact zone created by the lake drawdown is limited to a zone that extends about 4-5000 feet from the Lake Toho shoreline. Outside this drawdown zone, the elevation of the groundwater table depends only on climatic conditions. Even for long and severe drought conditions, similar to the 1998-2000 situation in Florida, both during the drawdown phase and during the lake refill phase the impact zone will not extend beyond 4000-5000 feet from the Lake shoreline.

1 INTRODUCTION

This report documents the building, calibration and application of an integrated surface water-groundwater model (ISGM) developed for South Florida Water Management District (SFWMD) by DHI and GeoModel, Inc. The ISGM is based on the MIKE SHE/MIKE11 code developed by DHI. The code has previously been applied to a number of SFWMD projects including the Alligator Lake drawdown study conducted jointly by SFWMD and DHI in 1998/1999. The MIKE SHE/MIKE11 code has the capability of simulating the major flow components of the hydrologic cycle, which makes the model very well suited for lake drawdown studies and, in particular, refill scenarios. The lake refill process is a complex interrelationship between climate and surface and sub-surface runoff processes combined with the operation of hydraulic control structures. A correct simulation of the lake water level and the aquifer recovery process requires and integrated modeling approach and a detailed description of the storage and hydraulics of lakes, canals and hydraulic control structures.

1.1 Background and Objectives

Lake Tohopekaliga (Lake Toho) is one of the larger lakes in the Kissimmee Chain of Lakes (see Figure 1-1). The Kissimmee Chain of Lakes is located in the upper Kissimmee Basin that extends from Orlando southward through Lake Kissimmee covering portions of Osceola, Orange, Polk and Lake Counties. These lakes feed the Kissimmee River, forming the headwaters of the greater Kissimmee-Okeechobee-Everglades ecosystem. Major lakes in the chain include Kissimmee, Toho, East Lake Toho, Hatchineha, Cypress, Gentry and Alligator.

Historically the lakes fluctuated between two and ten feet seasonally, providing natural cleansing and drying out which sustained the natural flora and fauna. The natural water level fluctuations supported the fishery and wildlife habitat, but made residential and agricultural developments difficult if not impossible due to flooding. After severe floods in the 1940's the lake water level fluctuations were controlled by improving canal conveyance and by introducing a number of hydraulic control structures (gates) and today the lake water level regime is largely controlled by the operation of these gates.

Lake water level drawdown help to reestablish and sustain fish and wildlife habitats. Controlled extreme drawdown is the management technique currently used to mimic the natural cleansing and drying process. During a drawdown lake levels are lowered up to six feet below their normal low pool stage and while the lake levels are low, organic matter and shoreline vegetation are physically removed. Lake water levels will be kept low for as much as 60-90 days in order to allow exposed sediments to dry out promoting die-off of undesired vegetation and the development of native vegetation regimes. Subsequently the downstream regulation gates are closed and the lake recovers back to its normal regulation scheme. Depending on the climatic conditions this recovery process may go on for several months or longer.

The Florida Fish & Wildlife Conservation Commission has planned and extreme drawdown for Lake Toho starting in November 2001. Traditionally the Commission sponsors the drawdown projects while federal and local government organizations support the projects, for instance, with technical expertise. The present project is funded by SFWMD in support of the drawdown study.

The proposed Lake Toho drawdown study would temporarily modify the normal lake water level regulation schedule to 48.5 feet. The normal regulation schedule varies between 52-55 feet.

The objectives of the present study is to develop an integrated surface water-groundwater model (ISGM) with the ability to predict potential impacts of the lake drawdown on groundwater levels in the surrounding region.

1.2 Structure and Content of this Report

The present report consists of a main report and a number of appendices.

The Executive Summary provides a brief 2-page summary of the main conclusions of the project.

Chapter 1, Introduction (this chapter)

Chapter 2, Model Formulation, describes the model formulation process and conceptual model building that forms the basis for the mathematical model.

Chapter 3, Model Building, describes how the conceptual model was implemented in a mathematical model of the Lake Toho area. The chapter also outlines the data that were used to build the model.

Chapter 4, Calibration and Validation, describes the model calibration and validation approach as well as the calibration results.

Chapter 5, Scenario Simulations, describes the selected model scenarios as well as the hydrologic impacts of the various scenarios.

Chapter 6, Conclusions, summarizes the findings and main conclusions made during the model formulation, building, calibration, validation and application phases.

The main report is supported by a number of Appendices that are referred to in relevant Sections. The Appendices contain additional information about data and data processing as well as additional outputs (graphics). Finally a CD-ROM has been submitted with all model data and GIS data.

2 MODEL FORMULATION

Prior to building a mathematical model of a hydrologic system the main features and driving forces of the natural hydrologic system must be understood. Without understanding at least the overall functioning of the natural hydrologic system an adequate mathematical model cannot be developed. This understanding of the hydrologic system is typically based on reviews of past study documents, field data reviews and field trips obviously supported by general hydrologic experience and engineering understanding.

Once the natural hydrologic system is understood and described a conceptual model can be established. A conceptual model is a simplified yet functioning model of the natural hydrologic system. The conceptual model must include the main features and driving forces of the natural hydrologic system and still be suitable for implementation in a mathematical model.

When the conceptual model is developed it can be implemented into a mathematical model. Thus, in principle, any modeling study includes the following phases:

- Develop understanding of the natural hydrologic system

- Formulation of a conceptual model

- Mathematical model building and model application

2.1 Understanding of the Hydrologic System

The following section describes in brief the principal functioning of the surficial aquifer system and the surface water drainage system. This understanding forms the basis for establishing the conceptual model of the project area.

The project area covers an area of about 1,100 square miles. The area is drained by a number of major lakes that are connected through a network of channels and hydraulic control structures. The Alligator chain of lakes is located in the eastern part of the model area. Alligator Lake forms the headwaters of this lake system and from Alligator Lake the water may flow either north to Lake Mary Jane or south towards Lake Gentry. The major flow is however southwards to Lake Gentry and further to Lake Cypress. The chain of lakes flowing north from Alligator Lake consists of Alligator Lake, Lake Lizzie, Coon Lake, Trout Lake, Lake Joel, Lake Myrtle, Lake Mary Jane which connects to Lake Hart. The western chain of lakes begins with Lake Hart, continues with Ajay Lake, East Lake Toho and Lake Toho, discharging into Cypress Lake. From Cypress Lake the chain continues with Lake Hatchineha and, finally, Lake Kissimmee (Guardo, 1992). Lake water levels are predominantly controlled by the operation of hydraulic structures (gates).

The surficial aquifer varies in thickness from around 20 feet to 300 feet. The aquifer consists predominantly of sandy and silty sediments with horizontal hydraulic conductivities on the order of 1-100 feet/day. Hydraulic gradients are generally small but around the lakes there are rather steep hydraulic gradients. This indicates that the aquifer has a relatively low permeability and that the lakes probably receive most of their inflows from surface water drainage systems (creeks, ditches, and canals) rather than as direct sub-surface inflows. These rather steep gradients, caused by the relatively low permeabilities of the aquifer, also suggest that lake water level variations will only affect a very narrow zone around the lakes. Thus the aquifer dynamics are predominantly a function of rainfall and evapotranspiration although surface water drainage features have significant local effects.

The surficial aquifer is primarily drained by surface water drainage features but it also provides a net recharge to the Upper Floridan aquifer. Past studies indicate recharge rates on the order of 1-2 inches/year on average for the project area. In the Reedy Creek basin and on the west side of Lake Toho there is a discharge zone where the surficial aquifer receives water from the Upper Floridan.

The predominant land uses in the project area are agriculture (27% of the project area), wetlands (25 %), urban and built-up (16%), upland forest (14%) and water (12%). Irrigation is not a significant factor in the area but it will play a role locally in irrigated agricultural areas as well as landscape and golf course irrigation. Urban areas constitute a significant part of the model area. Urban areas will have small-scale drainage and water storage features that cannot be described in the model in detail.

The driving force is the rainfall and ET ratio. In the dry season (November-April) the actual evapotranspiration exceeds the rainfall leaving a water deficit. There is essentially no groundwater recharge during the dry season. Groundwater recharge takes place during the wet season from May through October. Typical groundwater level fluctuations from dry to wet seasons are 3-6 feet.

The topsoils of the area are predominantly sandy and infiltration through the unsaturated zone is fast (days) and a few days without rainfall leaves the topsoil dry. In order to model this relatively fast recharge process as well as the groundwater level fluctuations detailed rainfall and evapotranspiration data are needed. The model uses daily data.

2.2 Conceptual Model

A conceptual model is a simplified, but functional, description of the natural hydrologic system. The conceptual model needs to represent the main features and driving forces of the natural system and be suitable for implementation in a mathematical model. For the Lake Toho ISGM the conceptual model must consider:

- Overland sheet flow and depression storage

- Infiltration and storage in the unsaturated zone

- Groundwater flow, storage and potential heads

- River/canal flow and water levels and hydraulic control structures

- Evapotranspiration losses

- Effects of drainage

- Effects of irrigation water allocation

- Dynamic exchange between unsaturated zone-groundwater (recharge)

- Dynamic exchange between aquifers and wetlands/rivers/canals (seepage)

- Dynamic flow exchange between flood plains, rivers, overland and wetlands.

To cover all processes with one modeling system, the combined MIKE SHE/MIKE 11 modeling system was selected. The modeling system is an integrated and distributed, physically based, finite difference modeling system (see Section 3.1).

2.2.1 Model Area

The Lake Toho model must be able to simulate both the drawdown process and the refill process. The duration of the refill period will obviously depend on the amount of surface and groundwater runoff to the lakes. The runoff depends on the climatic conditions (rainfall and ET) before and during the refill period. In order to use the model to study different refill (climate) scenarios the basins that drains to the lakes must be included in the model. In addition the model area must be sufficiently large to cover the area of potential impacts.

Based on these considerations the model area shown in Figure 1-1 was defined. The study area generally follows the topographic watershed of Lake Cypress except along the southern boundary where the model area simply was delineated by a straight line going East-West just south of Lake Cypress.

A fundamental model assumption is that the net groundwater flows across the model boundary is close to zero.

2.2.2 Surface Water

The major lakes in the model area together represent large water storage. Under normal meteorological conditions it can take the Lakes several months to recover from minimum operational level to maximum operational level. Thus in order to model, in particular, the lake and aquifer recovery process, the storage capacity of the lakes needs to be represented in the model. Moreover, the surface water system is heavily regulated by numerous hydraulic control structures that also need to be physically represented by the model.

The model area also comprises numerous minor lakes and wetlands, which are essentially just depressions filled by groundwater during high stage periods. Those lakes do not represent a significant conveyance capacity and will not contribute directly to runoff to the major lakes in the central part of the project area and they are not regulated by hydraulic control structures. This depression storage is included in the model through the overland flow model and, provided that the topographic data are sufficiently precise and that the groundwater level is modeled correctly, these minor lakes should be reproduced by the model during high groundwater stages. Thus, lake storage capacity that may tend to attenuate and delay peak runoff volumes is included in the integrated model.

A number of minor creeks and sloughs drains to the major lakes and may contribute with significant runoff to the lakes. However, available data does not justify a detailed physically based description. Those drainage features are modeled in a simplified manner using MIKE SHE's drainage option. Essentially the drainage option allows groundwater to be routed quickly to, for instance a lake, during high water stages when the groundwater level exceeds a specified drainage level. Thus the drains represents, in a conceptual manner, near surface and surface runoff in ditches, creeks, sloughs etc.

Based on these considerations it was chosen to include only the major lakes as well as the interconnecting canals. Thus, the model represents the main storage and conveyance capacity of the hydrologic system as well as the regulating mechanisms that controls the surface water flow regime. Figure 3-7 illustrates the layout of the surface water model.

2.2.3 Groundwater

The purpose of the model is to model only impacts on the surficial aquifer system. The Floridan aquifer can, however, not be completely ignored, as there is some exchange of water through the Hawthorn formation. In most of the project area the surficial aquifer recharges the Upper Floridan aquifer. Suggested recharge rates are on the order of 0-5 inches/year (Aucott, 1988) and (Planert and Aucott, 1985). This may constitute a relatively large portion of the excess rainfall (rainfall minus actual evapotranspiration) perhaps on the order of 10% of the excess rainfall. From Lake Toho and further south towards Lake Kissimmee the Upper Floridan aquifer recharges the surficial aquifer. Rather than including an extra calculation layer in the model the exchange with the Upper Floridan aquifer will be described using a general head boundary condition. Flows between the aquifers are calculated based on the head gradient between the surficial and the Upper Floridan aquifer and a conductance, where the conductance represents the Hawthorn formation.

The head in the Upper Floridan aquifer will be kept constant. The head was developed based on field data and represents low stages in the Floridan aquifer in order to promote outflows from the surficial aquifer rather than inflows.

The groundwater table in the surficial aquifer tends to follow the surface topographic features. Thus it is assumed that a zero-flow condition can be adopted along all model boundaries.

2.2.4 Infiltration and Evapotranspiration

The unsaturated zone model and the evapotranspiration models are closely linked in MIKE SHE as the actual ET depends on the soil-moisture regime in the root-zone. The main input parameters are soil-physical properties for the unsaturated zone flow model and potential evapotranspiration and vegetation parameters for the actual ET calculation. The need for conceptualization is limited, as the unsaturated zone model was established using distributed soil maps and land use maps in combination with rainfall and evapotranspiration data available within the project area.

The soil types in the project area are predominantly sandy and little capillary rise occurs. Thus the unsaturated zone model will ignore capillary rise which makes the mathematical solution of the governing flow equation simpler and faster.

MIKE SHE's irrigation module was adopted for calculation of irrigation demands. Demand calculations was based on actual simulated soil-moisture deficit in the root zone. Irrigation water will be considered a water import assuming that water is pumped from the Floridan aquifer and that water shortage will not occur.